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(56) Documents cited
EP 0190829 A2 EP 0099494 A2 WO 86/07445 A1
US 5107316 A US 4636082 A US 4449535 A

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UK CL (Edition L) G1A ACD ACJ ADE ADK ADM ADR ATH
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(54) **Optical fibre sensors**

(57) An optical fibre sensor arrangement (50) in which optical cables (54, 56) are mounted at an angle relative to one another in a plastic block (52), having a polished end face (62). Each cable (54, 56) has its end face angled relative to its longitudinal axis so that it lies in substantially the same plane as the end face (62) of the block (52). This arrangement provides a greater region where the incident light and reflected light overlap and hence improves the sensitivity of the sensor. A chromogenic or liquid sensitive fluorescent coating can be applied to the end face (62). The sensor is suitable for monitoring changes in intensity and/or wavelength of light reflected from a sample (64).

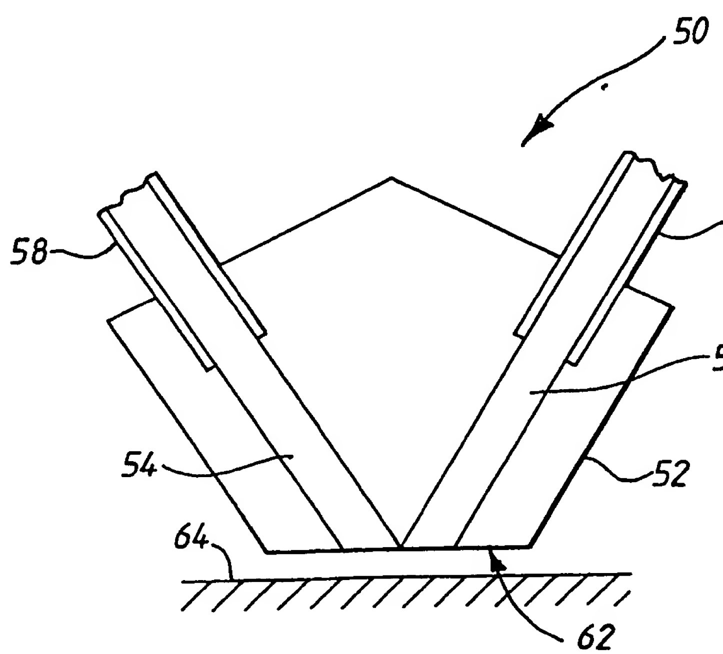

Fig.6.

GB 2 265 711 A

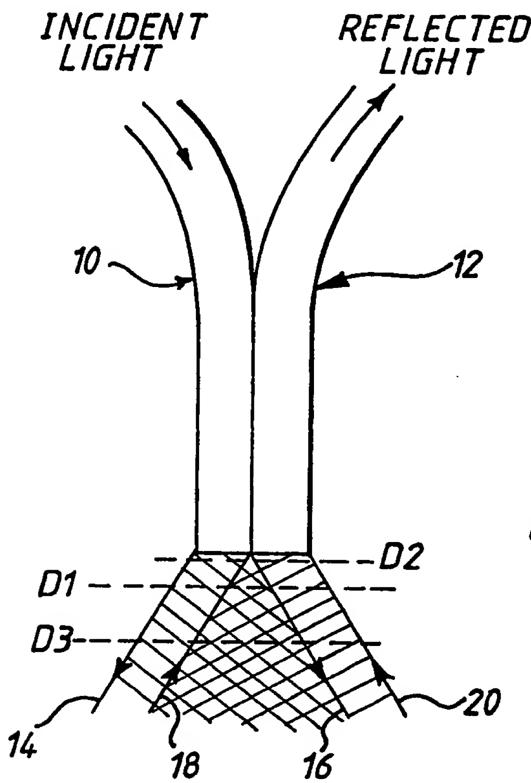
INCIDENT LIGHT
REFLECTED LIGHT
10
12
D2
D1
D3
14
18
16
20

Fig.1.

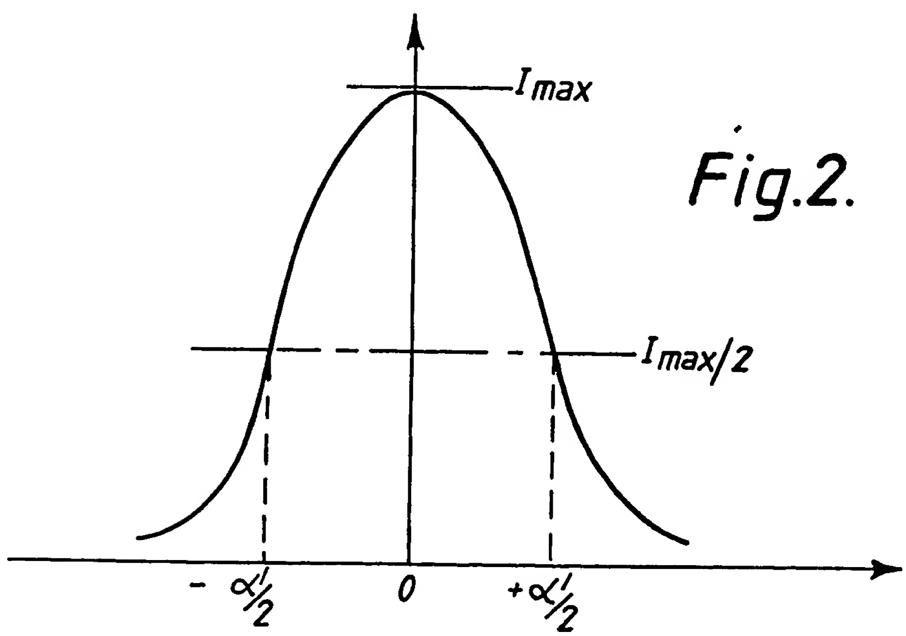
Imax
Imax/2
- α/2
0
+α/2

Fig.2.

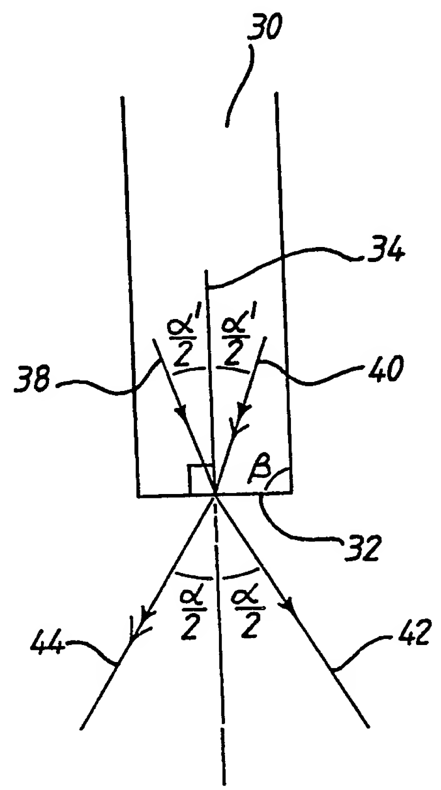
30
34
$\frac{\alpha'}{2}$ $\frac{\alpha'}{2}$
38
40
β
32
$\frac{\alpha}{2}$ $\frac{\alpha}{2}$
44
42

Fig.3.

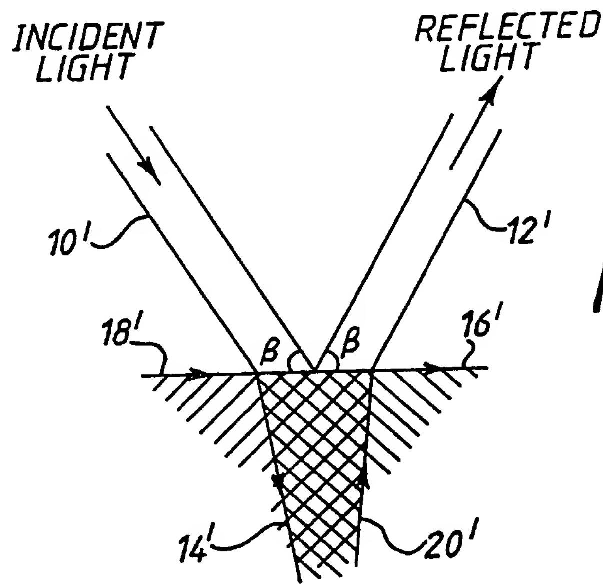
INCIDENT LIGHT
REFLECTED LIGHT
10'
12'
18'
16'
β β
14'
20'

Fig.4.

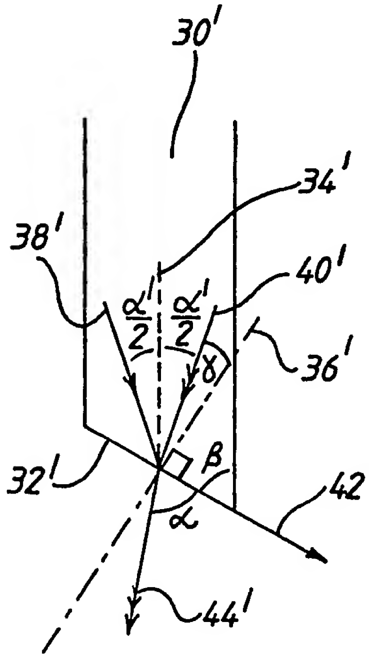

Fig.5.

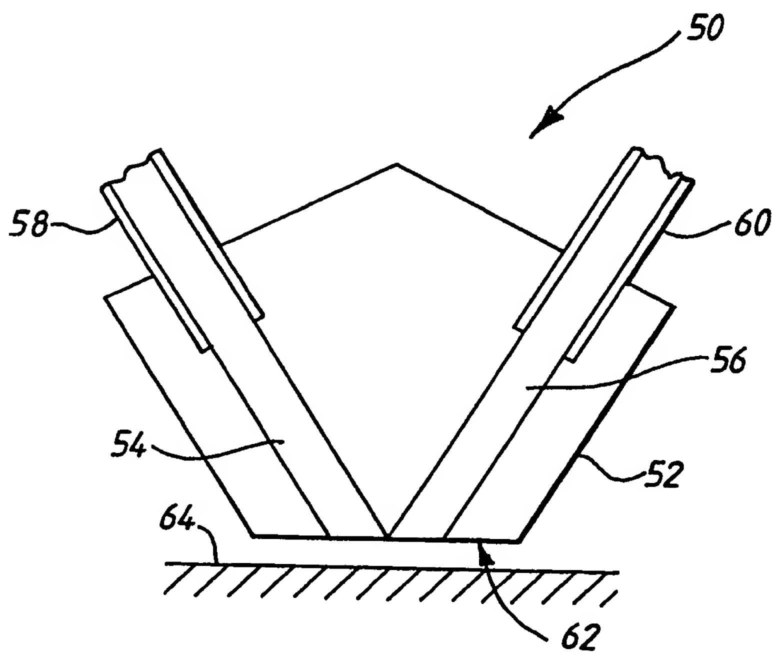

Fig.6.

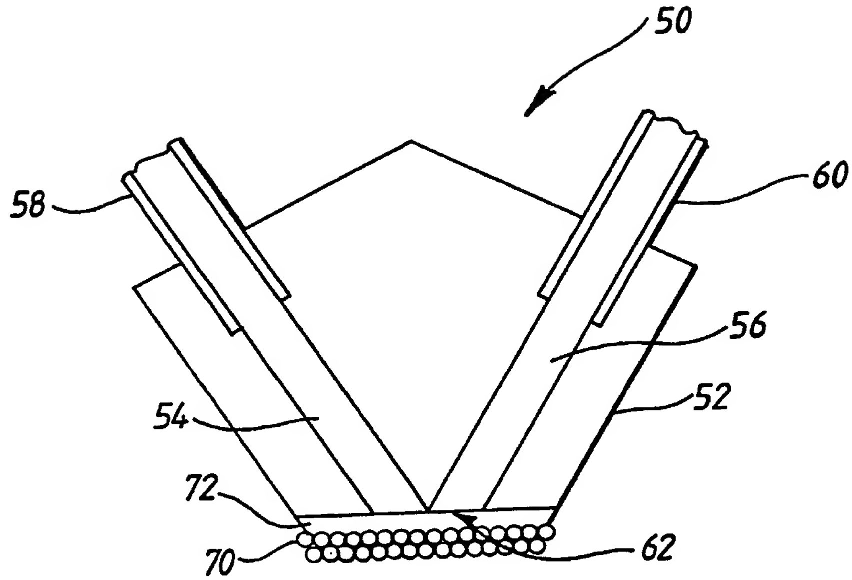

Fig.7.

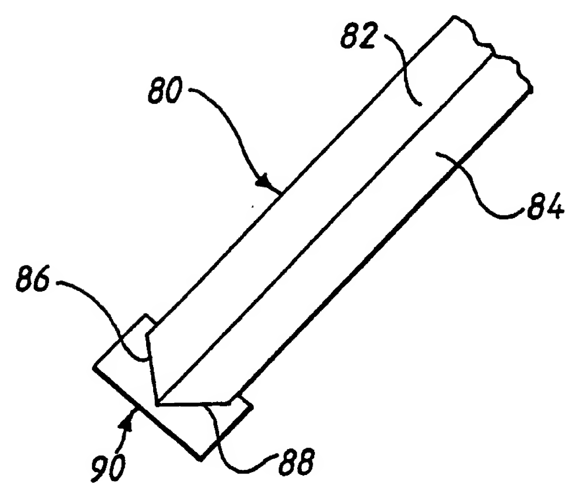

Fig.8.

OPTICAL FIBRE SENSORS

The present invention relates to optical fibre sensors.

Optical fibres are well known and have many uses. Generally, optical fibres are used to transmit light from one location to another.

In sensor applications, optical cables are used. In some of these applications, light is transmitted from a light source on to a sample and then light reflected from the sample is transmitted to processing apparatus. Each optical cable which transmits and receives reflected light may comprise either a single optical fibre or a multi-fibre arrangement.

Some sensor arrangements utilize a single optical cable both to transmit the light to the sample and to transmit the reflected light to the processing apparatus. In other arrangements, two optical cables are utilized - one for transmitting light from the light source and one for transmitting the reflected light from the sample. In either case, the light incident on the sample forms an emergent cone of light. The light reflected from the sample may be random due to scattering at the sample surface, but the optical cable will only be capable of picking up and transmitting light from a cone adjacent to its free end. This cone defines a zone of sensitivity. The efficiency of the sensor is related to the overlap of the emergent cone and the cone defining the zone of sensitivity.

In these known sensor arrangements, the end of the fibre is cut perpendicular to its longitudinal axis and in the case of multiple fibre sensors the longitudinal axes of the fibres are parallel to one another. In use, the optical cable (single fibre or

multiple fibre) is positioned so that its longitudinal axis is perpendicular to the sample surface. This results in the overlap between the emergent cone and the cone defining the zone of sensitivity being relatively small as the end(s) of the cable is reached, and as a result the efficiency is quite low.

It is therefore an object of the present invention to provide an optical sensor arrangement in which the efficiency is improved. This can be achieved by increasing the overlap between the emergent cone and the cone defining the zone of sensitivity.

US-A-4 830 458 discloses an arrangement for connecting optical fibres with one another to increase the exit angle of the light. In the arrangement described in US-A-4 830 458, a planar end face of a light-conducting optical fibre is manufactured so that the each fibre discharges light into the end face at an angle to the longitudinal axis of the fibre which is not 90° to the end face. This change of angle is achieved either by grinding the end face at an oblique angle relative to the longitudinal axis of the optical fibre or by winding each fibre therein as a helix around the longitudinal axis, the end face being perpendicular to that axis. In each case, the end face of the optical fibre is connected to another optical fibre which has its end face perpendicular to its longitudinal axis and the fibres arranged therein parallel to the axis.

According to one aspect of the present invention, there is provided an optical sensor arrangement comprising at least one optical cable for transmitting light from a light source on to a sample and for receiving light from the sample, the optical cable having a longitudinal axis and an end face,

characterized in that the end face is arranged to be at an angle to the longitudinal axis which is not 90°.

By this arrangement, the overlap between the emergent cone and the cone defining the zone of sensitivity, as discussed above, is much increased.

Advantageously, the angle which the end face makes with the longitudinal axis is chosen so that light emerging from the cable is at the grazing angle for the material from which the cable is made. Preferably, the angle is 66°.

Two optical cables may be provided, at least one cable having an end face angled with respect to its longitudinal axis. The optical cables may be aligned so that the respective longitudinal axes are angled relative to one another, or alternatively, they may be aligned so that the respective longitudinal axes lie parallel to one another.

Moreover, a sensitive membrane may be arranged adjacent the end face of each cable which interacts with a sample being tested.

For a better understanding of the present invention, reference will now be made, by way of example only, to the accompanying drawings in which:-

Figure 1 illustrates a conventional optical fibre sensor comprising two optical fibres and illustrating the emergent cone emerging from one fibre and the cone defining the zone of sensitivity of the other fibre;

Figure 2 illustrates the light profile produced from a single optical fibre;

Figure 3 is a simple ray diagram illustrating the light paths of a beam leaving a single optical fibre and passing into air;

Figure 4 illustrates an optical fibre sensor arrangement constructed in accordance with the present invention and shows the emergent cone and the cone defining the zone of sensitivity;

Figure 5 is similar to Figure 3, but illustrates the situation for a first embodiment where a single optical fibre sensor is constructed in accordance with the present invention;

Figure 6 illustrates a second embodiment of an optical fibre sensor configuration constructed in accordance with the present invention;

Figure 7 is similar to the configuration shown in Figure 6, but with a modification to the end face; and

Figure 8 illustrates a third embodiment of an optical fibre sensor configuration constructed in accordance with the present invention.

Figure 1 illustrates a conventional optical fibre sensor arrangement. The arrangement comprises two optical cables 10, 12, cable 10 providing incident light for a sample (not shown) and cable 12 receiving light reflected from the sample. Naturally, each cable 10, 12 may comprise one or more individual optical fibres which transmit incident light to or receive reflected light from the sample.

Lines 14, 16 denote boundaries of an emergent cone of light which is emitted from cable 10. Similarly, lines 18, 20 denote boundaries of a cone defining a zone of sensitivity from which reflected light is transmitted away from the sample. As shown in Figure 1, each cone extends away from its respective end of the cable 10, 12 and the zone of overlap is defined by the boundaries denoted by lines 16 and 18.

If lines are drawn parallel to the end faces of the cables 10, 12 at varying distances away from the faces, as indicated by D1 and D3 in Figure 1, different areas of overlap between the emergent cone and the cone defining the zone of sensitivity are obtained. In particular, at the position indicated by dotted line D3, a relatively larger area of overlap is obtained than at the position indicated by dotted line D1. Naturally, the light intensity at D3 is less than that at D1.

As a consequence, if the sensor formed by the two cables 10, 12 is substantially close to a sample, that is, at the position indicated by D2, there is a very small area of overlap between the two cones.

Figure 2 illustrates a plot of intensity against angle measured from a longitudinal axis extending through a single optical fibre. As shown, maximum intensity, I_{max}, is obtained when the light travels along the axis itself, and as the angle from the axis is increased, there is a drop in intensity. At the points indicated by the line $I_{max}/2$, half angles, $+\alpha'/2$ and $-\alpha'/2$ are obtained which correspond to a limit over which useful light makes only a small contribution to the total light incident on the sample or received therefrom.

As shown in Figure 3, for an optical fibre 30 having an end face 32 at an angle β to its longitudinal axis 34, the rays incident on and passing through the fibre-air interface are shown. (In a conventional optical fibre, $\beta = 90°$, and this is the case illustrated here.) Rays 38, 40 incident at angle $\alpha'/2$ to the longitudinal axis 34 (which coincides with a normal to the interface between the optical fibre and the air) are refracted away from the normal as

they pass through the interface and emerge at an angle $\alpha/2$ (which is greater than $\alpha'/2$) to the normal. (Ray 38 emerges as ray 42 and ray 40 as ray 44 as shown.) This is in accordance with the standard relationship (Snell's Law) between the angle of incidence (i), the angle of refraction (r), the refractive index of the fibre material (n_i), and the refractive index of the external medium (n_r) (which may be air), and is:-

$$n_i \sin i = n_r \sin r \quad (1)$$

For the case where the optical fibre is made from polymethylmethacrylate (PMMA), whose refractive index is 1.49 and where the external medium is air (refractive index of 1), an angle of incidence of 18° (corresponding to $\alpha'/2$) will give an angle of refraction ($\alpha/2$) of 28°.

However, if the optical fibres were positioned relative to the sample surface at an angle β which is less than 90°, there is a substantial change in the overlap between the emergent cone and the cone defining the zone of sensitivity. This is shown in Figure 4.

In Figure 4, two optical cables 10', 12' are shown which are angled to one another and to the sample surface (not shown). The emergent cone is defined by the lines 14', 16' and the cone defining the zone of sensitivity as 18', 20'. As shown in this Figure, the overlap between the two cones defined by lines 14', 16' and 18', 20' is different to that described with reference to Figure 1. The overlap is shown by the cross-hatched region between lines 14' and 20'.

Accordingly, if the sample surface is positioned so that it almost coincides with the free ends of the cables 10', 12' (that is, substantially

close to lines 18', 16'), a relatively greater area of overlap is obtained.

Referring now to Figure 5, a simple ray diagram is shown in relation to a single fibre 30'. The fibre 30' has an end face 32' and a longitudinal axis 34'. In this case, β is not 90° (in accordance with the invention) as described previously, and the longitudinal axis 34' no longer coincides with the normal 36' to the fibre-external medium interface as before. Rays 38', 40' are still at angles $\alpha'/2$ to the longitudinal axis 34'. However, the angle of incidence for ray 38' is now $\alpha' + \gamma$, and the angle of incidence for ray 40' is determined by the relationship:

$$\gamma = 90 - (\beta + \alpha'/2) \qquad (2)$$

In accordance with the present invention, β can be chosen so that ray 42' emerges from the fibre-external medium interface at a grazing angle to the end face 32', and the angle of incidence of ray 38' is determined by the following relationship (in accordance with equation (1)):-

$$\alpha' + \gamma = \sin^{-1}(n_r/n_i) \qquad (3)$$

where n_i is the refractive index of the fibre, n_r the refractive index of the external medium, and the angle of refraction is 90°.

If values of α' and n are known, γ can be calculated using equation (3). β can then be determined using equation (2).

Figure 6 illustrates a practical fibre optic sensor arrangement 50 in accordance with the present invention. The fibre optic sensor arrangement 50 comprises a plastic block 52 in which two optical cables 54, 56 are mounted, each having an associated sheath 58, 60. End face 62 of the block 52 is polished. As shown, the cables 54, 56 are angled to

the end face 62 and hence also to the sample surface 64.

As described above, light from a light source (not shown) is directed down cable 54 to the end face 62 of the block 52, and on to the sample surface 64. Light reflected from the surface 64 is then collected by cable 56 and transmitted to an analyzer (not shown).

Figure 7 illustrates another practical arrangement which is similar to that shown in Figure 6. Like components will be identically referenced. In this arrangement, a chromogenic reagent 70 is coated substantially close to the end face 62 of the block 52 including the fibres, but is separated from the end face 62 by a thin transmissive medium 72 of low refractive index, such as air.

In operation, the end face 62 of the block 52, together with the chromogenic reagent coating 70, is placed in a liquid sample, and according to the nature of the liquid sample, the coating 70 changes colour. This change in colour is transmitted to the analyzer for analysis as before via cable 56.

However, in this case, the light is not necessarily reflected from the sample surface but from the reagent coating 70 which changes in accordance with the nature of its interaction with the liquid sample.

In this arrangement, as the end faces of the cables are aligned with the end face 62 of the block 52, it is relatively easy to apply a coating thereto. However, it is to be noted that the coating is not limited to a chromogenic coating and could be a material which fluoresces when in contact with a liquid sample.

Figure 8 illustrates a further arrangement 80 in which the two cables 82, 84 are arranged to be parallel to one another. As before, end faces 86, 88 of the cables are angled to the respective longitudinal axis as shown. A membrane 90 is mounted on the end of the cables 82, 84 as shown which is operable to retain a sensitive coating (not shown) which interacts with a liquid sample as described above. This arrangement has the advantage that a very thin sensor can be provided.

It is to be noted that the coating 70 need not be chromogenic, but could be a coating which fluoresces under certain conditions. In this case, the analyzer would be set up to detect a change in the fluorescent properties of the coating.

Furthermore, a sensor constructed in accordance with the present invention is not limited to the detection of reflected light (as described with reference to the embodiment of Figure 6), but may be used to detect any change between the incident light and the received light to determine the nature of the material, solid or liquid, which is being sensed. In particular, the sensor arrangement described above can be used to detect changes in wavelength, changes in intensity or a combination of both wavelength and intensity.

CLAIMS:

1. An optical sensor arrangement comprising at least one optical cable for transmitting light from a light source on to a sample and for receiving light from the sample, the optical cable having a longitudinal axis and an end face,

characterized in that the end face is arranged to be at an angle to the longitudinal axis which is not 90°.

2. An arrangement according to claim 1, wherein the angle is chosen so that light emerging from the cable is at the grazing angle for the material from which the cable is made.

3. An arrangement according to claim 2, wherein the material comprises polymethylmethacrylate.

4. An arrangement according to claim 3, wherein the angle is 66°.

5. An arrangement according to any one of the preceding claims, wherein two optical cables are provided, at least one of the optical cables having an end face angled with respect to the longitudinal axis.

6. An arrangement according to claim 5, wherein the longitudinal axes of the optical cables are aligned to be angled relative to one another.

7. An arrangement according to claim 5, wherein the longitudinal axes of the optical cables are aligned to lie parallel to one another.

8. An arrangement according to any one of claims 5 to 7, wherein a sensitive membrane is arranged adjacent the end face of each cable which interacts with a sample being tested.

9. An arrangement according to any one of the preceding claims, wherein each optical cable comprises one or more optical fibres.

10. An optical sensor arrangement substantially as hereinbefore described with reference to Figures 6, 7 and 8 of the accompanying drawings.

Patents Act 1977 Examiner's report to the Comptroller under Section 17 (The Search Report)	Application number GB 9306353.5
Relevant Technical fields (i) UK Cl (Edition L) G1A (ACJ,ADK,ADR,ADE,ADM,ACD, ATH) (ii) Int Cl (Edition 5) G01N **Databases** (see over) (i) UK Patent Office (ii)	Search Examiner S J MORGAN Date of Search 25 MAY 1993

Documents considered relevant following a search in respect of claims 1-9

Category (see over)	Identity of document and relevant passages	Relevant to claim(s)
X,Y	EP 0190829 A2 (GOULD) see abstract and Figure 3	X:1 Y:8
X,Y &	EP 0099494 A2 (COMPUR) see whole document	X:1-6,9 Y:7,8
X,Y	WO 86/07445 A1 (OPTIMA) see whole document, especially page 9, lines 12-15 and Figure 5	X:1-7,9 Y:8
X,P	US 5107316 (SIEMENS) see Figure 4 and column 4, lines 42-50	X:1,7 Y:7
X,Y &	US 4636082 (COMPUR) see whole document	X:1-6,9 Y:7,8
X	US 4449535 (ALCATEL) see Figures 3 and 4 in particular	X:1,9

Category	Identity of document and relevant passages	Relevant to claim(s)

Categories of documents

X: Document indicating lack of novelty or of inventive step.

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